LA-UR-20-23934

Approved for public release; distribution is unlimited.

Title:	SRF Resonators for a bi-directional Energy Ramping Upgrade of the Isotope Production Facility Beamline at LANL
Author(s):	Krawczyk, Frank L.
Intended for:	Sharing with external collaborator with the purpose to develop new proposals to DOE-NP
Issued:	2020-05-29

Disclaimer:
Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy under contract 89233218CNA000001. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

DOE Cover Page

The project title: ***SRF Resonators for a bi-directional Energy Ramping Upgrade of the Isotope Production Facility Beamline at LANL***

Applicant/Institution: Dr. Frank L Krawczyk, AOT-HPE, Los Alamos National Laboratory
Street Address/City/State/Zip: LANL, AOT-HPE, MS H851, Los Alamos, NM 87545
Postal Address: LANL, AOT-HPE, P.O. Box 1663, Los Alamos, NM 87545

Administrative Point of Contact: Don Rej, (505) 665 1883, drej@lanl.gov
Lead PI name, telephone number, email: Dr. Frank Krawczyk, (505) 667 1958, fkrawczyk@lanl.gov

DOE National Laboratory Announcement Number: **LAB 14-1082**
DOE/Office of Science Program Office: **Office of Nuclear Physics**
DOE/Office of Science Program Office Technical Contact: **Dr. Manouchehr Farkhondeh**

Introduction

The LANL Isotope Production Facility (IPF) is one of the two high-current proton linear accelerators operated under the auspices of the DOE Office of Nuclear Physics Isotope Development and Production for Research Applications Program. The IPF beamline operates with a fixed 100-MeV energy proton beam, diverted from the LANSCE accelerator and guided towards the isotope production target station (Figure 1). The fixed beam energy limits the number of isotopes that can be produced at IPF, and adversely affects the purity of isotopes produced at non-optimal energies.

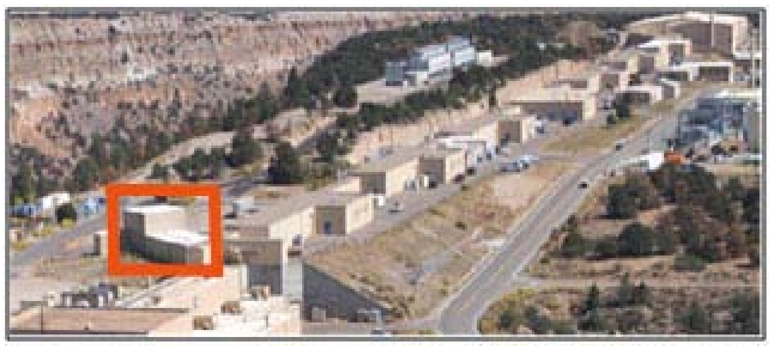

Figure 1: The IPF facility is to the left of the LANSCE main linac in a separate building.

In particular, the IPF program is receiving increasing numbers of requests for high purity isotopes such as Np-236 (national security applications) and Re-186 (medical therapy). These are typically produced via (p,n) and (p,2n) nuclear reactions, requiring very tight control of the incident energies on the production targets to ensure an end product with a high radionuclidic purity. It is well known that this level of energy control cannot be achieved when a 100 MeV beam of mono-energetic protons is degraded to the required energies, typically below 30 MeV, as too much energy spread is acquired. Operating the IPF beamline at lower, mono-energetic beam energies such as at 40 MeV will allow the required tight energy control in target assemblies to ensure a high purity product.

In addition, NP has requested a LANL/BNL/ORNL collaboration focus on establishing a national large-scale production capability for the therapy isotope Ac-225. Recent nuclear cross section measurements done at LANL show that due to a steep rise in production cross section towards higher proton energies (See Figure 2), proton beams at energies substantially greater than 100 MeV will be highly beneficial for Ac-225 production [AC255]. Such higher-energy beams cannot be delivered to IPF at present. Lower-energy beams (70 MeV and 40 MeV) can be delivered but only in sole-use mode; all other LANSCE users must be offline during 70 MeV or 40 MeV operation.

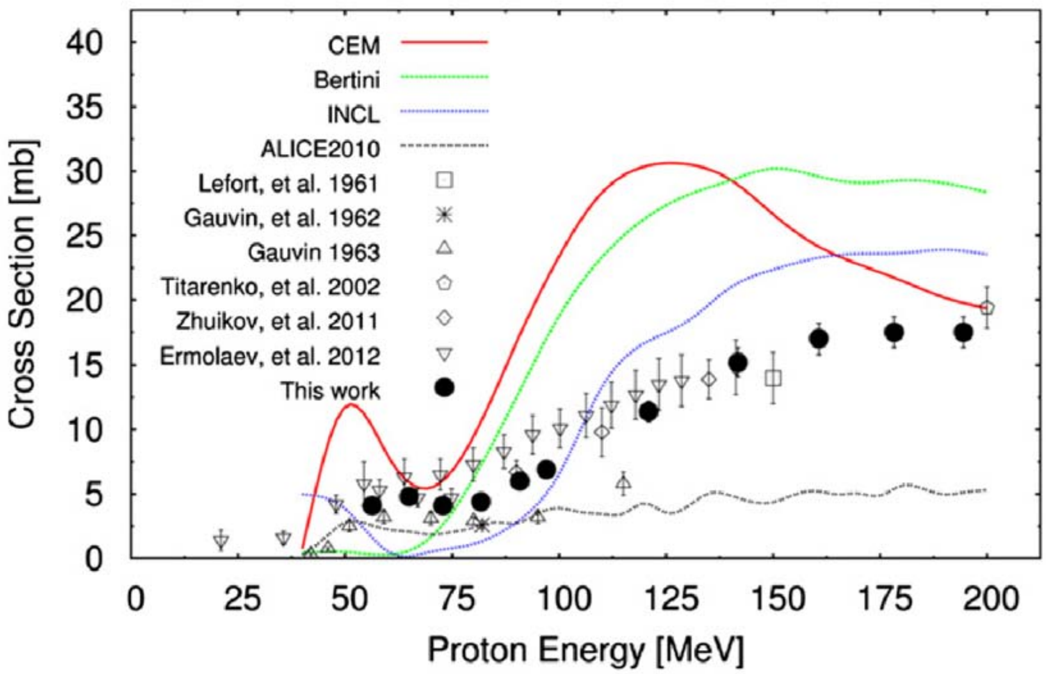

Figure 2: Experimental and theoretical cumulative cross sections for the formation of ^{225}Ac by the proton bombardment of thorium [AC255].

The addition of an RF accelerator/decelerator section onto the IPF beamline that could reduce the beam energy down to 40 MeV, or increase it up to 160 MeV, would achieve both objectives in a way that is transparent to other LANSCE users. A preliminary design concept [LA-UR-13-26568] for a dedicated beamline modification showed that such a "bi-directional" approach might fit into the available beamline space (< 15m), but that this would be challenging from an available space perspective.

Objectives/aims of the proposed project

The objective of the proposed work is to design RF structures for a credible IPF beamline design incorporating the ability to set the output proton beam energy at different values matched for optimal production of specific isotopes. This represents a significant extension of existing capabilities of the IPF beamline for NP customers. The work will focus on the RF section, which is the most space-consuming part of the beamline; for the rest of the beam transport we will assume the beam optics as derived for the conceptual design referenced above. Within these boundaries, both bi-directional (on one beamline changing the energy from 100 MeV up or down in the range 40-160 MeV) and uni-directional energy slew configurations (a single beamline either decelerating the beam from 100 MeV down to 40 MeV or accelerating the beam up to 160 MeV) will be evaluated and suitable RF structures will be identified and designed. The preliminary work done on the bi-directional 40-160 MeV case has shown that this versatile upgrade option is feasible, while challenging from a beamline space perspective. Therefore, it must be pointed out that beam energies marginally above 40 MeV are also very useful. Hence a modification of the first option employing a bi-directional design for the case X-160 MeV, where X can range from 40 to 50 MeV, will also be considered. *The deliverables for the first year effort shall be compact beamline and RF cavity designs for each feasible option, with sufficient detail to support fabrication and testing of prototype resonators in a* *follow-up effort. The deliverables would also provide supporting information to prioritize options and downselect the most suitable one, enabling a more detailed design and full costing.*

Description of the work

Operation of the IPF beamline at energies lower than 100 MeV currently requires modification of the LANSCE accelerator's nominal operating configuration. Doing so is difficult to schedule over extended periods of time, as all other downstream users are adversely impacted. Operation of the IPF beamline at energies greater than 100 MeV is currently impossible. The proposed work would make use of presently unused space in the IPF beamline to modify the energy of the IPF beam without impacting other LANSCE users. Figure 3 shows that at present the IPF beamline consists mainly of drift space. Populating the drift space with RF cavities and focusing magnets provides an opportunity to change the beam energy independent from LANSCE. The challenge is obtaining a useful energy change in the space available between the LANSCE beam line and the IPF target.

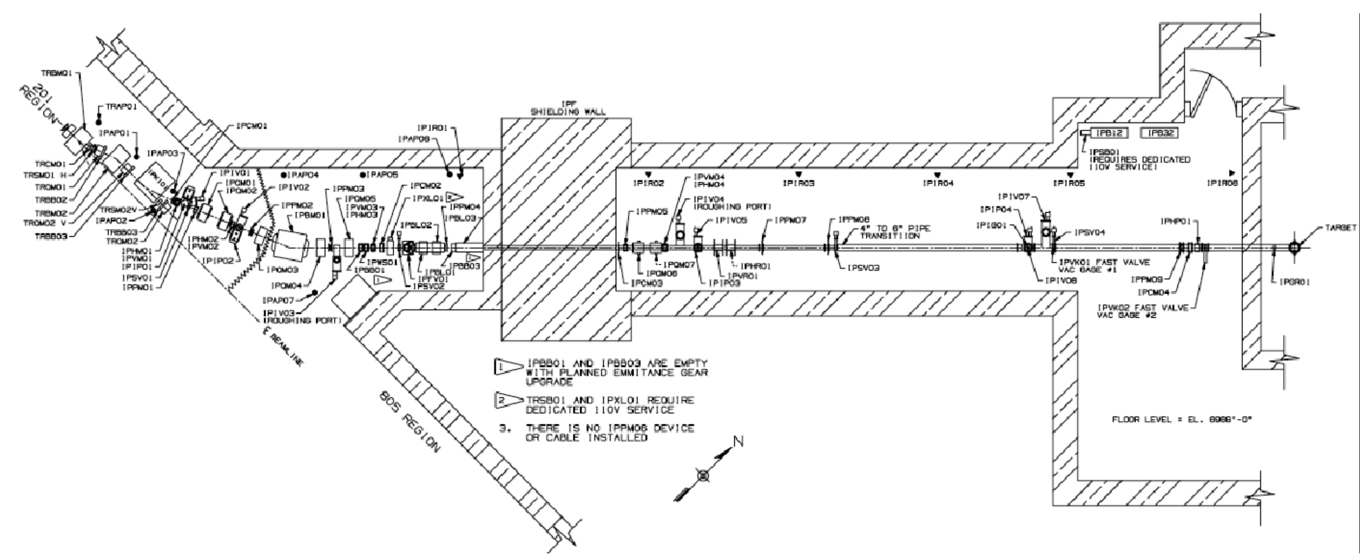

Figure 3: The present beamline layout transports the beam from LANSCE to the IPF target on a mostly empty beamline that consists of a matching section, some focusing magnets and the raster magnet to control the flux onto the target.

The proposed work focuses on using high-gradient superconducting RF (SRF) structures, providing the greatest potential for delivering the maximum energy change within the restricted space.

Three different beamline configurations are considered. First, coverage of the full range of energies from 40-160 MeV will be referred to as bi-directional operation and is the preferred solution since it supports the entire range of new customer interests. This scenario will also include the option of relaxing the 40 MeV requirement for the sake of fitting into the limited space. The remaining two scenarios are uni-directional operation, either for deceleration only (100 to 40 MeV) or acceleration only (100 to 160 MeV).

Bi-directional operation: The first, most flexible scenario uses an RF section that can increase or decrease the beam energy on the same beamline, depending on the phasing between the beam and RF fields. In acceleration mode the beam energy could be increased by up to 60 MeV, delivering up to 160 MeV proton beams to the target. In deceleration mode (see Figure 4) energy would be removed from the beam, permitting delivery of proton beams down to a beam energy of 50 - 40 MeV. A beamline with this capability could serve customers for all needs presented in the introduction.

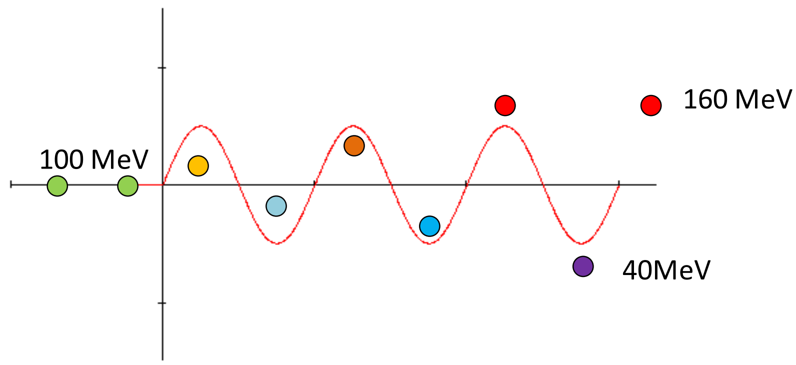

Figure 4: In phase, the RF cavities will transfer energy to the particle beam (green --> red); out of phase, the beam will transfer energy to the RF cavities (green --> purple).

Uni-directional acceleration/deceleration: As an alternative to bi-directional operation, the new beamline could focus on providing optimal energy increase *or* decrease, but not both. High production rates could be achieved for the Ac-225 medical therapy isotope for an optimal beam energy above 100 MeV [AC255], or a deceleration-only beamline could be operated to support medical isotope production or national security applications requiring beam energies down to 40 MeV. A uni-directional approach is attractive as it reduces the number and complexity of the associated RF systems. Such options may be attractive in fiscally constrained environments.

Velocity grading: In the energy range of interest the proton beam velocity changes strongly with the beam energy. For instance, a 100 MeV proton travels at 43% of the speed of light; a 40 MeV proton is moving at 28% of c, and a 160 MeV proton at 52% of c. To address this effect, "graded" structures are often used, wherein the structure length is matched to the beam velocity for optimum energy transfer. This approach would be used for the uni-directional operating modes, where either the length of the RF structures increases (acceleration) or decreases (deceleration) along the beam line. This approach could however not be used for the bi-directional mode of operation, as both acceleration and deceleration would need to be performed by the same RF structures. Thus the three scenarios require three different RF structures: uniform structures for bi-directional operation; positively graded structures for uni-directional acceleration and negatively graded structures for uni-directional deceleration.

RF frequency choice: IPF typically operates with 625 μs macro pulses at a 40 Hz rep-rate for a 2.5% duty cycle. The nominal average current of 250 μA translates to a 10 mA peak current. To be able to maintain the original pulse format, peak and average currents, we are opting for spoke resonators at the same RF frequency used by the upstream DTL section of LANSCE: 201 MHz.

Resonator geometry: Based on the frequency choice and a consideration of the low beam energy, the most suitable (for high gradient) SRF structures are spoke resonators [Delayen]. Elliptical resonators would be too big at this frequency, and at the low beam velocities ($0.28 < \beta = v/c < 0.52$) would be very inefficient. Multi-cell structures typically have real-estate gradients that increase with the number of cells. Generally speaking, however, the velocity acceptance of a structure is inversely proportional to the number of cells in the structure (Figure 4). Thus, a long, multi-cell structure is not an appropriate choice for any of the scenarios we are considering.

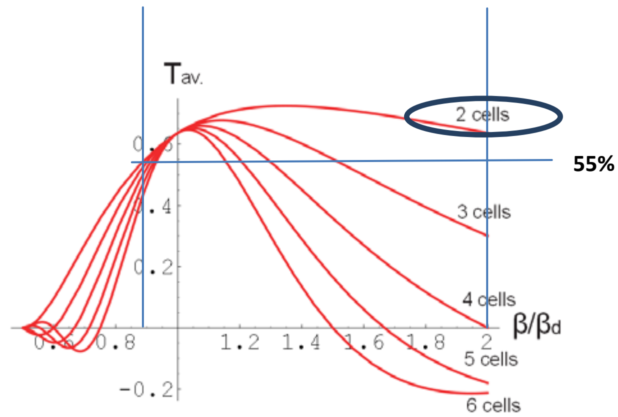

Figure 4: Transit time factor (efficiency) for a range of multi-cell resonators as a function of normalized β.

The ideal RF structure length is given by integer multiples of $\boldsymbol{\beta_d * \lambda/2}$, where $\boldsymbol{\beta_d}$ is the normalized reference velocity for which the structure works best, $\boldsymbol{\beta}$ is the normalized beam velocity, and $\boldsymbol{\lambda}$ is the wavelength corresponding to the RF frequency of the resonator. The biggest velocity acceptance can be achieved for two-cell, single-spoke resonators that are the baseline for the work described here. An example geometry is shown in Figure 5. The velocity acceptance is considered acceptable for a transit-time factor (efficiency) of better than 55%. Short structures are important also for flexibility of operation: independently phased short structures can be properly tuned for setting any energy between 100 MeV and the final beam energy limit, whether accelerating or decelerating.

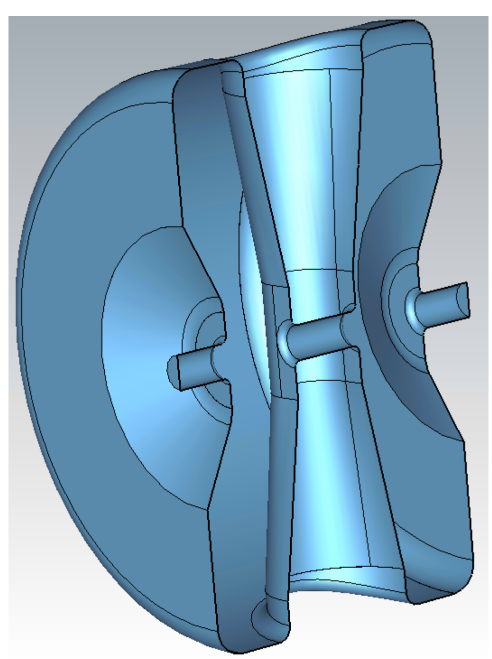

Figure 5: First proof-of-principle design of a spoke resonator at 201 MHz for a nominal beam velocity of β_d=0.283.

Design strategy: For all three scenarios SRF resonators will be selected that provide the shortest possible beamlines. In the bi-directional case this will be for a fixed β_d at the low end of the velocity range. Selection of a β_d at the lower end of the velocity range is required due to the skewed shape of the transit-time factor curve (Figure 4), keeping in mind that the structures must retain their efficiency when operating with 40-MeV beams at the end of the line. The preliminary design gives an optimum choice of β_d=0.283, providing an efficiency better than 55% for the full beam velocity range of 0.28 c to 0.52 c. For the uni-directional scenarios, a range of 2 – 3 different β_d values will be determined that best match the velocity change of the beam. No constantly-varying geometries will be considered; limiting the types of different cavities to be fabricated to a small number will help optimize overall cost. This stepped-β_d approach is common in the proton accelerator field [RIA] and provides structures that over the full velocity range have efficiencies much higher than 55%.

For each β_d and corresponding acceleration gap length, RF resonators will be designed for optimum performance. The performance criteria are RF frequency, maximum shunt impedance and minimum peak surface fields. (Table 1 shows representative parameters from the preliminary design concept.) These parameters determine the maximum gradient at which the cavities can operate. For low-β structures a prudent maximum for peak electric surface fields is 27 MV/m, a limit established during the prototyping phase for the SNS project [SNS]. For a peak surface field ratio of 2.61, this allows a peak on-axis gradient of ~ 10 MV/m and thus an energy change per resonator of about 3.6 MeV for a beam with $\beta \sim \beta_d$. As β varies from the optimum β_d the energy change will be reduced, as described by the transit time factor (TTF) change from 77% to 55%.

Based on the RF performance parameters, beam-dynamics simulations will be performed to model the transport of the beam from the matching section at the entrance to the IPF beamline, to the entrance of the raster magnet at the end of the IPF beamline. These beam-dynamics simulations will encompass the desired energy gain or reduction, proper phasing between beam and RF, and focusing and beam transport.

Table 1: Representative RF parameters for a β=0.283 spoke resonator

	Value	**Comment**
Beta $_{design}$ (β_d)	0.283	
Gap length [mm]	363	
Real-estate length [mm]	543	
Radius [mm]	412.7	
Aperture [mm]	25	Radius
Frequency [MHz]	201	
E_{peak} / E_{acc}	2.61	At nominal β_d
B_{peak} / E_{acc} [mT/MV/m]	7.49	At nominal β_d
R/Q [Ω]	224	At nominal β_d
TTF	0.77	At nominal β_d

Beam-dynamics Simulations: Standard accelerator design tools, such as Parmela [Parmela] or GPT [GPT], are readily available and well-suited to simulations of this type. As with any simulation, obtaining reliable output requires accurate input; in this case, the parameters describing the beam from LANSCE must be provided in order to obtain a realistic model of both the energy change and transverse dynamics. Existing transport and focusing elements must be incorporated, as well as information regarding whether those elements are movable or replaceable. Finally, design parameters and constraints for the final focus required at the target are needed.

Deliverables: For each of the three operating modes, the beamline layout and required length will be determined based on the selection of RF structure and operational parameters. As a result, for each scenario we will learn if a credible design can fit into the limited space in the IPF beamline. Minor parameter tweaks will be part of an optimization effort.

For the bi-directional operation, RF performance for the given best β_d and beam optics are the only adjustable parameters. These are complemented by the option to relax the lower energy bound. If a change of the low-energy point is necessary, the final design deliverables will include the resulting effect on the purity of the generated isotopes.

For the uni-directional cases the optimization effort is more flexible and elaborate. RF designs based on a variable set of β_d can be evaluated in an iterative process; the resulting lengths and achievable beam parameters are then used to determine the best performance given the available space. The graded-structure approach with its better velocity acceptance also adds the option to consider 3-gap, two-spoke SRF resonators, which improves the real-estate gradient, reducing the operation gradient and cryogenic cooling requirements. We do not consider it likely that for these cases any compromises in the achievable energy range will be required.

As an outcome of this iterative approach of RF structure design and beam dynamics, two very specific deliverables will be available at the end of one year for follow-on work:

- A selection of up to three beamline designs, with calculated on-target beam properties, from which a baseline design can be picked for determination of the full needs of the accelerator and all subsystems; and
- Corresponding detailed RF structure designs for the baseline of choice, for which prototyping can immediately be started upon additional funding.

Justification of the project

The proposed project addresses requirements of the 2007 NSAC Long Range Plan that encourages applications derived from basic research in nuclear science, as it leverages prior development of advanced RF structures (e.g. for RIA and FRIB) for extended capabilities of the LANL IPF facility [NSAC07]. More importantly it also supports the findings of the 2009 NSAC Final Reports on “Compelling Research Opportunities using Isotopes” [NSACI] and “Isotopes for the Nation's Future - A Long Range Plan” [NSACII] that recommend to “*invest in new production approaches for alpha-emitters with highest priority for 225Ac*”.

Present isotope production capabilities at the LANL IPF only cover a limited range of desired customer needs with relevance to medical or national security areas. In particular, the application of a novel 4-π cooled, 40 MeV irradiation capability to the production of novel isotopes for national security and medical applications may be required in the future. More importantly, the potential of future demand for Sr-82 and simultaneous demand for Ac-225 in out-years is an important driver for this design study. In IPF's current configuration, the production of Sr-82 and Ac-225 would compete for the high-energy (92-73 MeV) target slot. An energy upgrade would optimize production of Ac-225 in the 100-160 MeV range [AC255] while allowing optimized production of Sr-82 to continue in accordance with normal IPF operations.

The fixed-beam-energy operation at 100 MeV is sub-optimal for many isotopes. While there are different approaches to address this, the addition of RF resonators to change the beam energy on target seems to be very promising. It uses space that is already available on the IPF beamline, the configuration is totally transparent to LANSCE operation, and it preserves the operation of the IPF based on a linear accelerator, in which LANL is very experienced. Its implementation adds significant flexibility to the IPF operation, which would result in new customers and applications that potentially add new funding sources to the IPF operation.

The focus of the proposed work on the RF-structure and beam-dynamics studies gives a depth to the quality of the results that seemed superior to us in comparison with an overall system study, which would have to be much more simplistic within the expected funding limits.

Methods used

The work in the first year would be mostly theoretical, with physics and engineering simulations to design good quality SRF resonators, and beam-dynamics simulations incorporating the resonators' calculated electromagnetic fields. The design team has decades of experience in this type of work with proven results.

As a first step, analytically the β_d selections for all three operating scenarios will be firmed up from the previous design concept. The up-front work will also include nuclear physics simulations that provide optional relaxation of the low-energy boundary upward from 40 MeV, while still yielding acceptable purity isotopes at the lowest energy limit.

Beam dynamics simulations shall begin with generic cavity field models and magnetic fields for the optical beamline elements. The software packages used are Parmela, GPT or **elegant**; each has its particular strengths, and using several codes provides good cross-checking of the results. These simulations establish the basic requirements on RF resonators and beam optics that will be translated to space requirements and RF resonator performance needs.

RF resonators will be designed using established 3D electromagnetic simulation tools such as CST Design Studio [CST]. These provide all performance parameters for the operating modes, as well as for undesired modes that may require suppression. The RF design work will also generate information for other relevant considerations. These include RF loss information required for the cryo-module properties, CAD versions of the SRF resonator geometries for a fast-track evaluation of mechanical properties and fabrication considerations, and interfaces to power feeds and HOM damping, if this is required. As they become available, electromagnetic field maps from the RF resonator simulations will be incorporated into the beam dynamics simulations.

Much of the beam-dynamics and RF design work can be done in parallel, as many basic parameters are known from previous work or experience. This allows for a fast iterative process of beam-dynamics and RF simulations that cumulates in a final, self-consistent description of beam-transport and structure design.

Space requirements are an especially important aspect of this design project; our deliverables also include analytic estimates of cavity-to-cavity spacing (to evaluate cross-talk), determination of the use of normal or superconducting focusing magnets, the overall configuration of the cryo-modules that house the SRF cavities and, finally, any required new beam diagnostics and transport control magnets in addition to present components on the IPF beamline.

Results expected

Based on the good results from the preliminary design concept, we expect to achieve credible beam-dynamics and RF structure designs for more than one operating scenario. Neither the beam parameters nor the RF performance parameters are extremely challenging, putting the design work at an acceptable technical risk level. The results of the beam-dynamics studies are expected to be detailed enough to be immediately useful for an overall layout of the beamline and major subsystems in a follow-up effort. The RF designs will be detailed enough to facilitate follow-up with mechanical design and fabrication drawings after completion of the first year. The operating parameters will provide all information for determining power coupler requirements, the needs for higher-order mode (HOM) damping, RF power source and load parameters, cryogenic loads and cryo-module configuration. Thus the results of the first year effort should be sufficient to immediately support follow-up prototype testing and a fast-track determination of a suitable full IPF upgrade path based on the present location of IPF.

Alternate options

There are two primary alternatives for the IPF beamline RF structures. The first is the use of quarter-wave SRF resonators [Shepard] instead of spokes. This would require a trade-off between a slightly lower operating field gradient (and a corresponding increased length of the beamline) versus the advantages of radially more compact resonators. It should be noted that at 201 MHz, spoke resonators, while more compact than elliptical cavities, are already large in diameter.

The use of SRF resonators is beneficial, as these structures can achieve higher gradients than normal-conducting resonators. However, due to the need for a cryoplant to provide liquid helium, a superconducting system is arguably more complex than a water-cooled, room-temperature system. If normal-conducting structures were to be considered, the use of IH/CH structures, as for example investigated at LANL [Kurennoy] present the second option. Again, this choice represents a trade between structure gradient, available space, and overall system complexity.

We reserve consideration of these alternatives should the described design work reach limits that might be overcome with one of these alternate approaches. They will otherwise, however, not be considered for the proposed work.

Timeline

The proposed tasks start with nuclear cross-section simulations to understand the impact of specific beam energies on yield and purity of isotopes. Based on these results the three operating scenarios will have their own RF design tasks, beam dynamics simulations and generation of self-consistent beamline layouts (for all cases that fit into the beamline limitations), considering beam on target, the optimized RF resonators, cryomodule configurations and beam optics.

The described work will be performed by a team of scientists from LANLs’ C-IIAC (Inorganic Isotope & Actinide Chemistry) and AOT (Accelerator Operation and Technology) divisions, with some support functions. Dr Engle will contribute the nuclear physics expertise, Drs Krawczyk (PI), Lewellen and Tajima (Co investigators) are responsible for the RF structure, beam dynamics and cryogenics tasks. The timeline is given in Figure 6. To track progress, milestones have been set at approximately 4-month intervals; at each milestone, one of the three scenarios has been evaluated for feasibility within the available IPF beamline space.

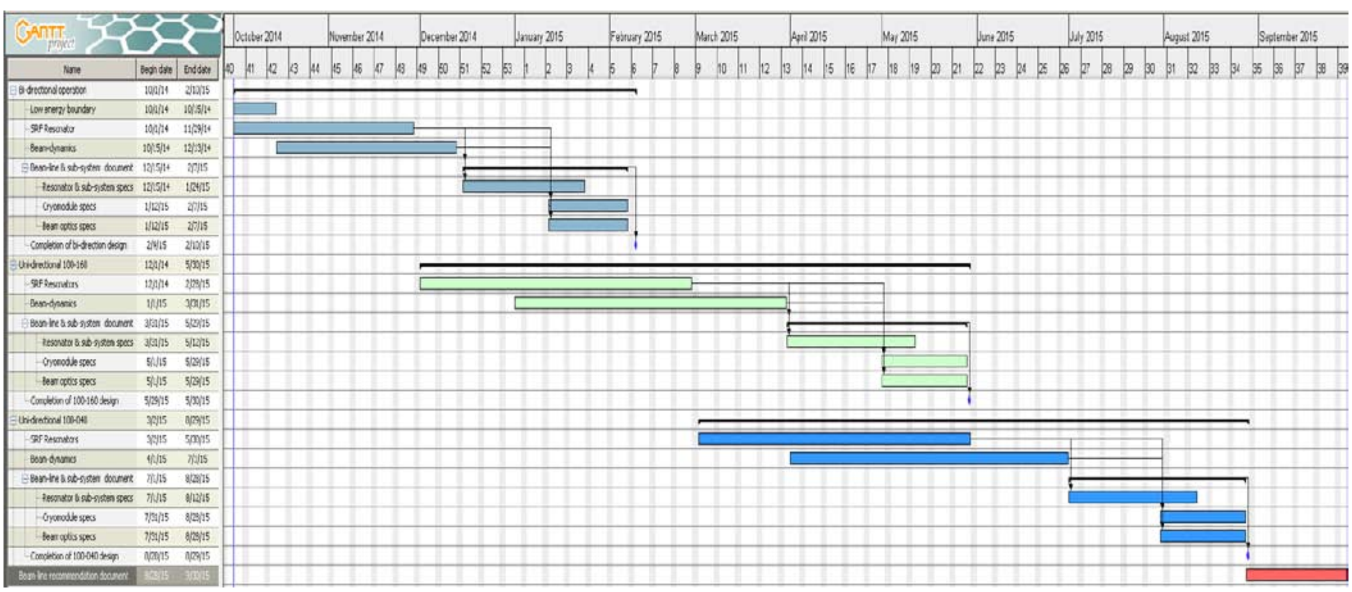

Figure 6: Timeline for design of three beamlines and the resulting recommendations for RF structures, beamline configuration and sub-system needs

Path forward after year one

The proposed work will conclude with detailed recommendations for suitable beamlines at the present location of the IPF. Based on NP Isotope Program customer needs and priorities, these results can form the foundation for a short-term down-select of a baseline IPF upgrade beamline and for a streamlined effort to configure and cost this beamline and the associated support systems. The RF resonators are also detailed for potential immediate start of a prototype fabrication and testing effort.

APPENDIX 1: BIOGRAPHICAL SKETCH FOR FRANK KRAWCZYK (PI)

Dr. Krawczyk has more than 20 years of experience at Los Alamos National Laboratory (LANL) in accelerator physics relevant to the LANL mission in accelerator technology. His experience spans RF structure designs for proton and electron linear accelerators and contributions extending beyond traditional accelerator work. He is involved in everyday management and operational tasks, including planning of theoretical and experimental work, resource planning, budgeting, sponsor interaction, mentoring, and teaching.

Education and Training:

1993-1996	Post-Doctoral Fellow, Accelerator Physics, AOT-1, LANL, Los Alamos, NM Electromagnetic simulations for novel RF structures
1989-1992	Research Assistant in "Theory of Electromagnetic Fields", University of Technology, Darmstadt, Germany
1990	PhD in Physics, University of Hamburg, Germany Thesis: "A Contribution to the solution of Maxwell's equations in unbounded domains"
1986-1989	PhD Student and student employee, Numerical Mathematics and Electromagnetic Theory, DESY, Hamburg (German National Laboratory)
1986	Physics Diploma, University of Kiel, Germany Thesis: "Wave phenomena in the layers of disk galaxies" (in German)
1981-1986	University of Kiel, Germany – Major: Physics, Minor: Mathematics

Research and Professional Experience:

2010-now	Staff member, High Power Electrodynamics, AOT-HPE, LANL, Los Alamos, NM Electromagnetic simulation work on novel RF structures (SRF spoke resonators and MW-class power couplers), antennas, and practical beamline components (Main thrusts: Navy Free Electron Laser (FEL), MaRIE X-ray FEL) Principle Investigator for the LANL Navy FEL project (since October 2013) Member of the LANL Navy FEL management team (since May 2012) Project leader for the "Technology Maturation" on the Navy FEL (since May 2012) Team-leader for diagnostics on the NCRF-injector beamline for ONR (2010-2012) Web-services for the international accelerator physics community through the LAACG, distribution/maintenance of LAACG software to the accelerator physics community
2005-2010	Staff member, High Power Electrodynamics, ISR-6, LANL, Los Alamos, NM Simulation and experimental work on the design and testing of novel RF structures (SRF elliptical resonators, SRF spoke resonators, RFQs) and antennas for NA22, DARPA, and the Navy-FEL (SRF spoke resonators, photo injectors, SRF elliptical resonators) Web-services for the international accelerator physics community through the LAACG, distribution/maintenance of LAACG software to the accelerator physics community
1996-2005	Staff member, Accelerator Physics, LANSCE-1, LANL, Los Alamos, NM Simulation and experimental work on the design and testing of novel RF structures for LANSCE (elliptical SRF resonators), Accelerator Production of Tritium (APT) (elliptical SRF resonators and MW-class power couplers), Accelerator Transmutation of Nuclear Waste (ATW) (SRF spoke resonators), NA-22 (mm-wave resonators and power tubes), DARPA, and Navy-FEL (spoke resonators and photo injectors) Provider of web-services for the international accelerator physics community through the LAACG

Publications:
F. Krawczyk, “Electromagnetic Simulations for the APT Cavities and Power Coupler", Invited talk at the 1998 APS Meeting, Columbus, OH, April 1998, LA-UR-98-933
F. Krawczyk, R. LaFave, K.C.D Chan, R. Gentzlinger, M. Madrid, D. Montoya, D. Schrage, A. Shapiro, T. Tajima, K. Shepard, "Evaluation and Testing of a Low-beta Spoke Resonator", Proceedings of PAC01, Chicago, USA
F. Krawczyk, R. LaFave, "Design of a low-beta 2-Gap Spoke Resonator for the AAA Project", Proceedings of PAC01, Chicago, USA
F. Krawczyk, "Status of Multipacting Simulation Capabilities for SCRF Applications", Proceedings of the 10th Workshop on RF Superconductivity, Tsukuba, Japan, September 2001, LA-UR:01-6447 (Invited talk)
F. Krawczyk, K.C.D. Chan, R.C. Gentzlinger, W.B. Haynes, J.P. Kelley, D.I. Montoya, E.N. Schmierer, D.L. Schrage, T. Tajima, "An Integrated Design for a Beta=0.175 Spoke Resonator and Associated Power Coupler", Proceedings of EPAC 2002, LA-UR:02-3150 (invited talk)
Frank Krawczyk, "Interface Issues Between Superconducting Cavities And Power Couplers", Invited talk at the Workshop on High Power Power Couplers, Jefferson Lab, Nov 2002, LA-UR-02-7890
Frank Krawczyk, "Multipacting Simulations for Power Couplers", Invited talk at the Workshop on High Power Power Couplers, Jefferson Lab, Nov 2002, LA-UR-02-6781
F. L. Krawczyk, D. C. Nguyen, B. Rusnak, E. Wright, “RF Design of a Spoke Resonator for High Power Free-Electron Lasers”, Proceedings of Linac08, Victoria, Canada
F. L. Krawczyk, D. C. Nguyen, “Spoke Cavities for High-current Accelerators”, Invited talk at DEPS12, Santa Fe, NM
J. Potter, F. L. Krawczyk, “Resonant Coupling Applied To Superconducting Accelerator Structures”, Proceedings of CAARI 2012, Fort Worth, TX (invited talk)

Synergistic Activities:

Dr. Krawczyk was organizer of the International “Workshop on the Advanced Design of Spoke Resonators" held in Los Alamos, NM, October 2002. I was also the editor of the proceedings, published as "Proceedings of the Workshop on the Advanced Design of Spoke Resonators", LA-14005-C, http://laacg.lanl.gov/spokewk/

Teacher of the class “Methods and Simulation Tools for Cavity Design”, at the Tutorial session at the 2011 International Superconducting RF Workshop, SRF2011, Chicago, IL, USA

He is regular reviewer for SBIR (Phase 1 and Phase 2) proposals in the areas of RF structures and numerical methods.

Over the years he has been reviewer for the following peer reviewed journals: NIM, PRSTAB, APS, PhysRev, JINST, IEEE

Dr. Krawczyk is mentor and teacher for young staff members, students and post-docs within the LANL Accelerator Operations and Technology Division on RF technology and RF design tools.

Collaborators and Co-editors:

Over the last four years the PI collaborated on technical work with the following individuals:
Chase Boulware, Niowave Inc.
Bruce Carlsten, LANL, AOT-DO
Jean Delayen, Old Dominion University
John Lewellen, LANL, AOT-HPE, former Naval Post Graduate School, Monterey
Robert Greegor, Boeing Corp.
Terry Grimm, Niowave Inc.
Douglas Holmes, Advanced Energy Systems
Nathan Moody, LANL, AOT-HPE
Dinh Nguyen, LANL, AOT-HPE
James Potter, JP Accelerator Works
Brian Rusnak, Lawrence Livermore Laboratory
Richard Swent, Naval Postgraduate School, Monterey
John Singleton, LANL, NHMFL
Tsuyoshi Tajima, LANL, AOT-MDE
Arthur Vetter, Boeing Corp.
Haipeng Wang, Jefferson Laboratory

Graduate and Postdoctoral Advisors and Advisees:
PI’s graduate Advisor: Prof. Dr. Thomas Weiland, University of Technology, Darmstadt, Germany
PI’s principle Postdoctoral Sponsor: Dr Robert Ryne, Lawrence Berkeley Laboratory

APPENDIX 2: CURRENT AND PENDING SUPPORT

PI's current major support for FY14:
Navy Free Electron Laser Project:

- This work is funded by the Office of Naval Research – Code 35
- Current funding: **$371k**
- Current person-months per year: **8**

Los Alamos Accelerator Code Group:

- This work is funded by irregular license income
- Current funding: **$40k**
- Current person –months per year: **2**

PI's concurrent submissions (for FY15 and later funding support):
LANL-LDRD Directed Research

- Applied for a funding level of: **$100k**
- Funding corresponds to **3** person-months per year

Navy Free Electron Laser Project:

- Applied for a funding level of: **$371k**
- Funding corresponds to **8** person-months per year

Appendix 3: Bibliography &References Cited

[AC255] J.W. Weidner, S.G.Mashnik, K.D.John, F.Hemez, B.Ballard, H.Bach, E.R.Birnbaum, L.J.Bitteker, A. Couture, D.Dry, M.E.Fassbender, M.S.Gulley, K.R.Jackman, J.L.Ullmann, L.E.Wolfsberg, F.M. Nortier, "Proton-induced cross-sections relevant to production of ^{225}Ac and ^{223}Ra in natural thorium targets below 200MeV", Applied Radiation and Isotopes 70 (2012) 2602)

[LA-UR-13-26568] L. Rybarcyk, F. Krawczyk, T. Tajima, D. Rees, P. Walstrom, D. Barlow, J. O'Hara, F. Shelley, M. Gulley, "IPF Energy Upgrade Scoping Study", LANL Report LA-UR-13-26568 to DOE-NP. The report can be accessed at http://www.osti.gov/scitech/biblio/1090644

[Delayen] J. Delayen, W. Kennedy, C. Roche, "Design and Test of a Superconducting Structure for High-velocity Ions", Proceedings of the 1992 linear accelerator conference, Nov 1992; 949 p; 1992 Linear Accelerator Conference; Ottawa, ON (Canada); 24-28 Aug 1992; AECL--10728(VOL.1,2)

[RIA] K. Shepard, "The RIA Driver Linac", Proceedings of LINAC2002, Gyeongju, Korea, pp596-599

[SNS] I. E. Campisi, S. Assadi, F. Casagrande, M. Crofford, G. Dodson, J. Galambos, M. Giannella, S. Henderson, M. Howell, Y. Kang, K. Kasemir, S. H. Kim, Z. Kursun, P. Ladd, H. Ma, D. Stout, W. Strong, Y. Zhang, M. Champion, "Status and Performance of The Spallation Neutron Source Superconducting Linac", Proceedings of PAC07, Albuquerque, NM, pp 2502-2504

[Parmela] Lloyd Young, Parmela Manual", LANL Publication LA-UR-96-1835, Revision December 1, 2005

[GPT] M.J. De Loos and S. B. Van der Geer. "General Particle Tracer: A new 3D code for accelerator and beamline design." *Proceedings of the fifth European Particle Accelerators Conference Sitges*. 1996. GPT is now a commercially available code; further information available at http://www.pulsar.nl.

[NSAC07] The Nuclear Science Advisory Committee, "Report of 2007 DOE/National Science Foundation (NSF) Nuclear Science Advisory Committee (NSAC) Long Range Plan", published at http://science.energy.gov/np/nsac/

[NSACI] NSAC Isotopes Subcommittee, "Compelling Research Opportunities using Isotopes", Final Report - One of Two 2008 Charges to NSAC on the National Isotopes Production and Applications Program, April 23, 2009, Page 3, published at http://science.energy.gov/~/media/np/nsac/pdf/docs/nsaci_final_report_charge1.pdf

[NSACII] NSAC Isotopes Subcommittee, "Compelling Research Opportunities using Isotopes", Final Report - Isotopes for the Nation's Future A Long Range Plan" Second of Two 2008 Charges to NSAC on the National Isotopes Production and Applications Program, August 27, 2009, Page 149, published at http://science.energy.gov/~/media/np/nsac/pdf/docs/nsaci_ii_report.pdf

[CST] Commercial software, Information available at http://www.cst.com

[Shepard] I. Ben-Zvi, J. Brennan, "The Quarter Wave Resonator as a Superconducting Linac Element", Nuclear Instruments and Methods 212 (1983) 73-79

[Kurennoy] S. Kurennoy, L. Rybarcyk, T. Wangler, "Efficient Accelerating Structures for Low-energy Light Ions", Proceedings of PAC07, Albuquerque, New Mexico, USA, pp 3824-3826

APPENDIX 4: FACILITIES & OTHER RESOURCES

Los Alamos National Laboratory has the requisite technical infrastructure and experience to reliably transition accelerator structures from initial design, through prototype testing, into operational status within a user facility. The LANL accelerator technical area, centered around the LANSCE accelerator complex, is home to the IPF beamline itself, a world-class SRF testing laboratory for individual cavities, and a shielded tunnel complex suitable for testing completed cryomodules.

As home to the Accelerator Operations and Technology Division, and specifically the High Power Electrodynamics group, the accelerator technical area also hosts subject-matter experts on all technical fields required to successfully complete the proposed work. In particular, the PI (Dr. Krawczyk) has world-leading experience in the design of SRF resonators for proton and ion applications. The other members of the proposal team are recognized experts in beam dynamics simulation and optimization (Dr. Lewellen), SRF operations and cryogenics (Dr. Tajima) as well as isotope production modeling (Dr. Engle). The team also has direct access to critical IPF beamline data, in particular both the design parameters of the existing IPF beamline and the parameters of the beam presently supplied by LANSCE to the IPF.

This environment naturally supports an efficient, success-oriented approach to perform both the accelerator layout and RF structure design with a potential follow-up execution of the project based on the results of the proposed work.

Appendix 5: Equipment

The work proposed, at this stage, focuses mainly on theoretical and engineering design work for an upgraded IPF beamline. As such, most of the required equipment consists of computer hardware (already existing) and software (some currently available, some to be purchased) to perform the required simulations.

Critically, however, the design team also has physical access to the IPF beamline, as well as its nominal design and beam parameter data. In the likely case that the new designs require modification to the existing beamline (i.e. repositioning of magnets), the ability to rapidly obtain data on as-built equipment location and specifications, and the potential for relocation or replacement, will notably improve the ability to validate design choices. Thus, while not strictly part of the required-equipment tally in the usual sense, the ability to locally access the IPF beamline itself, and its presently installed equipment, will play a key role in increasing our confidence in the proposed upgrade paths.

Appendix 6: Other Attachments

None